1914

A STUDY OF SOME WATER-TABLES AT GIZA.

By W. LAWRENCE BALLS.

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A STUDY OF SOME WATER-TABLES AT GIZA.

By W. Lawrence Balls.

Although the following account deals with minute details which are of direct interest only to the cultivator of a few feddans of land in Giza province, its publication seems advisable for several reasons.

The records are unique in that they were taken daily for four months. They were peculiar also in the frequency of the wells, there being a well to every two feddans of land.

The records obtained are interesting in that they show the water-table to be a singularly sensitive thing, but their importance consists in the proof which they provide of the main postulate on which the "Water-table Hypothesis" rested, viz., that the level of the subsoil water had been raised by irrigation. Of this postulate I wrote in 1910, "One might say that it is incapable of proof, owing to the absence of hydrological records . . . . in the meanwhile there is circumstantial evidence." In the end of 1911 I had given up hope of a direct proof, and wrote "The original hypothesis is still unproven, and must so remain, in the absence of extensive records to show the water-levels of past years, but so strong a case has been made out for the presumption that . . . . the proof may be regarded as exhaustive."

The unprovable is now proven, chance having caused me to take these well records in the only year that the Nile has remained low enough since 1809 to give them the desired significance, and the water-table hypothesis of cotton deterioration in Egypt is now complete from end to end.

It may perhaps be thought that I am asserting more than is justifiable, and disregarding the excellent work of Mr. Ferrar, in making this claim, but it should be remembered that in the preface to the latter's Lower Egypt report [1] it is explicitly stated "When Mr. Ferrar says that the water-table has been raised he refers, except where otherwise stated, to the formation of what is called the artificial water-table, and not to the increase in height of the latter itself, *although he believes that this also has occurred.*" The italics are mine. The wells numbered A, 1, and 5 in the following account are strictly natural-water wells, not even artificial, in so far as anything is natural in Egypt, and their level rose in 1913 to more than thirty centimetres above the water-table produced by outflow from the river situated only a kilometre away, this rise being distinct from and superposed upon, the rise due to the Delta Barrage, demonstrated in the Cairo wells by Mr. Lucas.

A last reason for publishing these records is that there seems to be a strong general resemblance between the conditions obtaining at Giza and those of the trial farm at Tayiba in the Sudan, both as regards the growth of the plants, and in indications of soil structure. The analogy need not be pushed too far, but in the course of a brief visit to the Gezira during January, 1914, I was most strongly impressed with its existence. This impression ran quite counter to my preconceived ideas, and it is not worth while to neglect any evidence which may bear upon it, however remotely.

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[1] Preliminary Note on the Subsoil Water in Lower Egypt and its bearing on the reported deterioration of the Cotton Crop, by H. T. Ferrar, M.A., F.G.S. Cairo, 1910.

SITE.

The land in question pertains to the Giza Cotton Station of the Ministry of Agriculture. Its nearest approach to the river on the east is about one kilometre away at Well No. 1. The wells form a chain at right angles to the river, (with two offsets) ending at the western boundary of the land, which is formed by the canal flowing on the east side of the Upper Egypt E.S.R. line, and lies mid-way between Bulak Dakroor and Giza stations.

Adjoining land to the south is formed by the School of Agriculture, and this particular land formerly constituted part of the old farm of the Khedivial Agricultural Society. Consequently it has the advantage of a long history, extending over some twenty years. This history is one of depreciation, the data for which are in the possession of the Society, I believe, and they show a fall in yield from above eight kantars to under five kantars of cotton per feddan. When the two farms of the School and of the Society were being similarly cultivated, the higher yields were obtained from the north end, viz., the Society's.

SOIL STRUCTURE.

At present the land consists of patches which would give more than ten kantars in normal cultivation, and of patches which could not be made to give more than five kantars at their best. The reasons for this will appear in the well-curves. There is tremendous local variation in the subsoil structure, which is largely masked... though evident... on the surface. I have found gradients of 1:1 at the junction of loam and sand two metres down. Two of the wells here recorded are only a few centimetres apart; one is six metres deep (the only deep well in the series) the other three metres. The deep well reaches into permeable strata, while its shallow companion is in impermeable clay. Ten metres only away from this pair I dug a hole to two metres, bored beyond to five metres, and drifted beyond the bottom of the bore with a gas-pipe "jumper" to thirteen metres without reaching the permeable bed which the deep well taps, although the jumper passed through three thin sand-beds below six metres; the water-table in the clay at the time this bore was made stood at two metres below the surface, while that in the deep well was only one metre below, so that the tapping of the permeable bed would have been shown by a gush.

The soil structure may be described from the superficial examination of samples as a sandy loam, with patches of silt and sand distributed unevenly, merging into heavier stiff loam and clay.

WELLS.

The five feddans around the laboratory were fitted with the deep well A., and five three-metre wells, Nos. 1-5, when the writer took it over in March, 1912. Records were taken weekly during that year and showed that A, 1, and 5 were in hydraulic continuity, while 2, 3, and 4 were isolated in clay. These three latter wells appeared to lie in a clay saucer. The saucer had been filled by the infiltration of water from outside during the flood of 1911, so that the foundations of the laboratory had to be laid in subsoil water; this though the land wsa fallow. In 1912 and 1913 the water never rose under the laboratory, from which it would appear that the inlet into this saucer lies above 17·70 A.S.L, which was the maximum recorded level of Well A. the soil surface being about 19·00 A.S.L.

Wells 1, A, and 5 showed reversal of gradient in 1912, though only 80 metres apart. During low stage the water-surface fell from 5 through A to 1, and reversed during flood.

In 1913 we attempted to locate the water-movements more accurately, by daily record and soil-survey. Additional wells were put in on 22 acres of new land which were taken over in February, being Nos. 6-16. The soil-surface falls about 10 cm. from No. 1 to No. 4, and rises again to the West Canal. The soil-survey was never completed, but a number of samples were taken and stored for physical analysis when time should permit.

During the year's working of this new land we found that a non-drying area could be marked off on the surface, especially after sowing berseem in the autumn. A similar area occupied the site of the laboratory. These wet patches are indicated approximately on the diagram Plate I, on which the positions of the wells are also shown. We made careful examination of these patches, puddled the misqas, and adjusted our waterings by simultaneous observations of tube-wells and of shedding from the plants. That our new style of agriculture was satisfactory is shown by the fact that in propagation work on this new land we obtained an average production per plant of 1,400 seeds, (equal to our maximum for selected normal plants in the Spacing Experiment) although 75 per cent of them had been re-sown a month after the critical sowing date, and some of these were badly stunted.

There is still room for plenty of soil-research in the area and in view of the nature of the well-records here published, I am inclined to think it would be worth while to make a soil-survey to four metres depth at not less than 50 metres interval, over these thirty feddans, and to continue the records.

Methods.—The wells were of the usual type as employed in the Survey Department work, and were all put down for me by Mr. Ferrar of the Department. The hole to receive the well was bored with an auger ; risk of clogging the gauze end is thus minimised. All wells were tested once a year by filling up with water and taking hourly readings. No. 4 is open to suspicion, and has been omitted, though not badly choked.

With the exception of Well A which was bored to six metres, all wells are *three metres deep* only.

A bench-mark at 19·105 metres was established for me by the Survey Department, and I personally levelled all the wells from this.

The records were taken weekly until July 17, 1913, when daily records were instituted with only one omission on September 9. Each day they were plotted by Mr. O. Weinsteiner, and any eccentricity in the curves was made the occasion for re-measurement. The curves here published (see Plate II) are traced direct from the working-diagram.

It hardly seems advisable to cumber this account with numerical statement of the 2,400 soundings embodied in the curves, but I shall have pleasure in doing so subsequently if they are needed by any investigator.

The actual soundings were taken by Shaaban Abd el Aal, Plant Observer, usually at about noon of each day.

The method of sounding was simple and satisfactory, with a small definite error, easily workable by one observer, instead of by the two required for the more precise plummet-and-tape method. A box-wood metre scale 4 mm. thick was

planed down to 5 mm. width, and a loose lead bob of 5 cc. volume was hung on the end. This scale was lowered into the well on the end of a light steel chain marked at metre intervals. One, two, or no metres of chain having been let down from the edge of the well-mouth, the ruler was drawn up, and the wetted length noted. Occasionally a mistake was made over the metres, which was easily checked when plotting. Otherwise the readings were correct to the half-centimetre at which they were read, as the curves will show.

Correction has not been made in these curves, except for reduced level, but a small error is involved by dipping the scale into the water, since the displacement of the scale and bob raises the level in the well. The corrections with the planed-down scale were slight, the maximum being only seven millimetres which is too small to show in the present plotting.

I venture to think the results show very well the quality of the work which can be done by a smart fellah using a suitable method, at a salary of £2 a month. The records themselves (once the wells were in), cost half an hour's labour per diem by the Plant Observer, and perhaps ten minutes by the clerk, or P.T. 150 in all, for the data here plotted.

That the final proof of the water-table hypothesis should have been obtained on the small plot of land whence it was first promulgated, is an interesting confirmation of my personal belief in the utility of concentration upon details, as against wide general surveys of a large area.

WELL-RECORDS. JULY 17th to NOVEMBER 25th, 1913. (See Plate II).

In order to compact the diagram the curves for each well have been stepped above one another, marking the base of 16 metres A.S.L. (except No. 3, for which the 17 m. base is given) for each well on the frame-lines. At the bottom of the diagram is a heavy line showing the published readings of the Nile gauge at Roda, some two kilometres south, and a cross-dashed line showing the level of a canal mentioned above as bounding the land on the west. This last is on a reduced scale; it was measured by the observer of the wells.

Another canal was also measured daily, viz., the larger of the two on the east boundary, but no connection whatever is shown anywhere between the movements of this and of the wells. It has therefore been omitted from the diagram. This Wakfs Canal is small in comparison with the West Canal.

The irrigation water actually used on the land was obtained from a third very small canal running side by side with the Wakfs Canal, but in the opposite direction, from the Giza Waterworks. This little canal was rarely empty, as it fed not only the land in question, but also the School of Agriculture, and the Horticultural Section. No effects were traceable to it, as distinct from those produced by its supply-water in the land misqas.

The well-curves in the figure have been arranged for convenience according to their relative freedom, from Wells A, 1 and 5 which tap permeable strata, to Wells 3, 2 and 8 which are solely influenced by surface water.

The dates of irrigation of the land by each well are marked on the curves by small circles to facilitate reference.

Well No. 7 was in dry land, near where new buildings were being erected, and the only surface water near it was several metres away in the Horticultural Section.

All other wells were on the margin of roads, and were earthed up so that no water could get down the bore hole outside the tube except accidentally.

Well A.—This deep well is entirely independent of surface irrigation. On a weekly curve it seems to be affected solely by the rise of the Nile, with a lag of about ten days. The daily records show that the West Canal rises are transmitted to it, 200 cm. on the canal causing 5 cm. on Well A at a distance of 520 metres. In addition to this cause, further sharp deflections as were produced on July 24th and Aug. 8th by another cause. This latter cause would appear to be nearer the well, since the peaks are sharper, and I at first attributed it to the Wakfs Canal, but wrongly. Nos. 1, 5, 6, 7, 14 and 16 are also affected by it, and possibly 11, but not 13 and 15.

The remarkable fact that this well rose in 1913 to a higher level than the Nile itself, which we had presumed to be the primary cause of its elevation, will be dealt with later.

Maximum reading in 1912. . . 17·70 A.S.L. (Roda. 18·33.)
,, 5-day mean in 1913 . 17·44 A.S.L. (,, 17·15.)

Well No. 1.—Is also entirely unaffected by surface water, and follows Well A to within a few centimetres. These two are obviously in direct communication through sandy beds over 160 metres.

The chief interest of this well lies in its position on wet land. The corner at which it is situated is one of the wettest spots after irrigation, indicating that the impermeable bed is near the surface. This well evidently goes through the bed into sand, and this corner of the land could therefore be drained by a sump not more than three metres deep.

Well No. 5.—Is very nearly like the two preceding wells, but is slightly affected by surface irrigation. Its point is evidently in communication with the sand-bed tapped by A and 5, directly or not, and bore-holes made around it in the course of small-plot experiments show that this bed comes rapidly up to the surface to the west of Well A, so that the land around No. 5 is beyond the edge of the clay saucer.

Though the behaviour of the wells when the land was heavily flooded for berseem is not particularly interesting, it will simplify matters subsequently if we now look at the behaviour of No. 5 at the end of October. An elevation of the West Canal had produced no effect upon it, since it was already at its full height, while the irrigation for berseem raised it 27 centimetres on October 29th, indicating a slight impermeability or more probably the normal difficulty of outflow through loam under a small head. On the 30th it had fallen halfway back, but on the 31st it rose again, coincident with a heavy irrigation around No. 7.

This watering of No. 7 may fairly be said, I think, to have leaked into No. 5, but it is at first sight equally likely that seepage from the S and SC misqas (i.e. South and South-Central, see Pl. I) was the cause. Against this we have the fact that these were not running fuller than usual, while misqa SC was at work nearly every other day of the year for the Horticultural Section; no such marked misqa effects are visible on No. 5 elsewhere, although there seem to be slight ones abundantly, so that our first explanation is probably correct, since the soil from 7 to 5 is all quite good and seems homogeneous.

On the other hand, water re-distributing its pressure between 7 and 5 should affect No. 6, which lies in a straight line between. Yet No. 6 shows not a trace of

such effect—this was the well which stood in dry land—and I have no hesitation in postulating an extra permeable bed of two, by which the water from 7 could affect 5 by going underneath or round 6. The postulate scarcely seems scientific, but the heterogeneity of the subsoil justifies it.

Well No. 6.- This appears at first glance to be like its predecessors, but closer examination shows that it is actually slightly isolated, being lower at low-stage than its position justifies. Apparently it is in loam, not freely connected with No. 5 through sand, and its catchment area can dry up a little faster than water can move in to replenish it. With a very slight head established the loss and gain balance, and No. 6 then moves with 1, A and 5.

It shows the West Canal effect more markedly, being nearer to the canal, a distance of only 300 metres separating them.

Well No. 7.—This resembles No. 6 in its general behaviour, and like No. 6 it rises to a higher maximum than the preceding wells. It is also affected by the same cause which we found acting on Well A in addition to the Nile and the Canal; with No. 7 we appear to be getting nearer to the origin of the disturbance, for the smooth sharp peak shown by A, 1 and 5 is tending to break down into separate peaks. It is almost impossible to ascribe this effect definitely, but inspection of the dates of irrigation seems to indicate that it is due to seepage from the SC misqa, beyond the Horticultural Section's land, where the misqa had been completely re-built in the spring. I am personally of opinion that a sand-bed comes up to the surface quite close to the fence, nearly due north of No. 6. The curve on July 21st to 24th, and August 5th to 8th, shows successive elevations of this well as the SC and NC misqas were filled and re-filled.

Wells 14 and 16.—These two may be discussed together. They both lie in the wet area of the new land, though not in the worst part, and they rise to the same maximum as A, 1, and 5. They do not fall to the same minimum, however, and it is quite clear that they are trapped in some way by impervious layers below, so that surface water cannot drain away freely. Of the two No. 16 is the less trapped.

Light might be thrown on the soil structure in this northern section, which is quite good land though not easy to work, if we could trace to its origin the slight rise in August 14th and 15th, which is shown by these two, and by 13, 6, and 7 only, though there may be a trace of it in Well A.

The misqa-effect was subjected to direct experiment in the case of these two wells by Mr. Holton, who took readings from them every three hours before and after filling the NC misqa, and showed that they were directly affected thereby. It should be remembered that the misqas were newly made in the spring, and that they were pierced in all direction by mole-cricket burrows, which we followed in some places to a depth of 75 cm. below the soil surface.

Wells 13 and 15.[1]—These also form a pair, the latter lying nearly in the centre of the worst part of all the land. Due north of No. 15, under the south bank of NC misqa, the surface water has stood for several days after watering.

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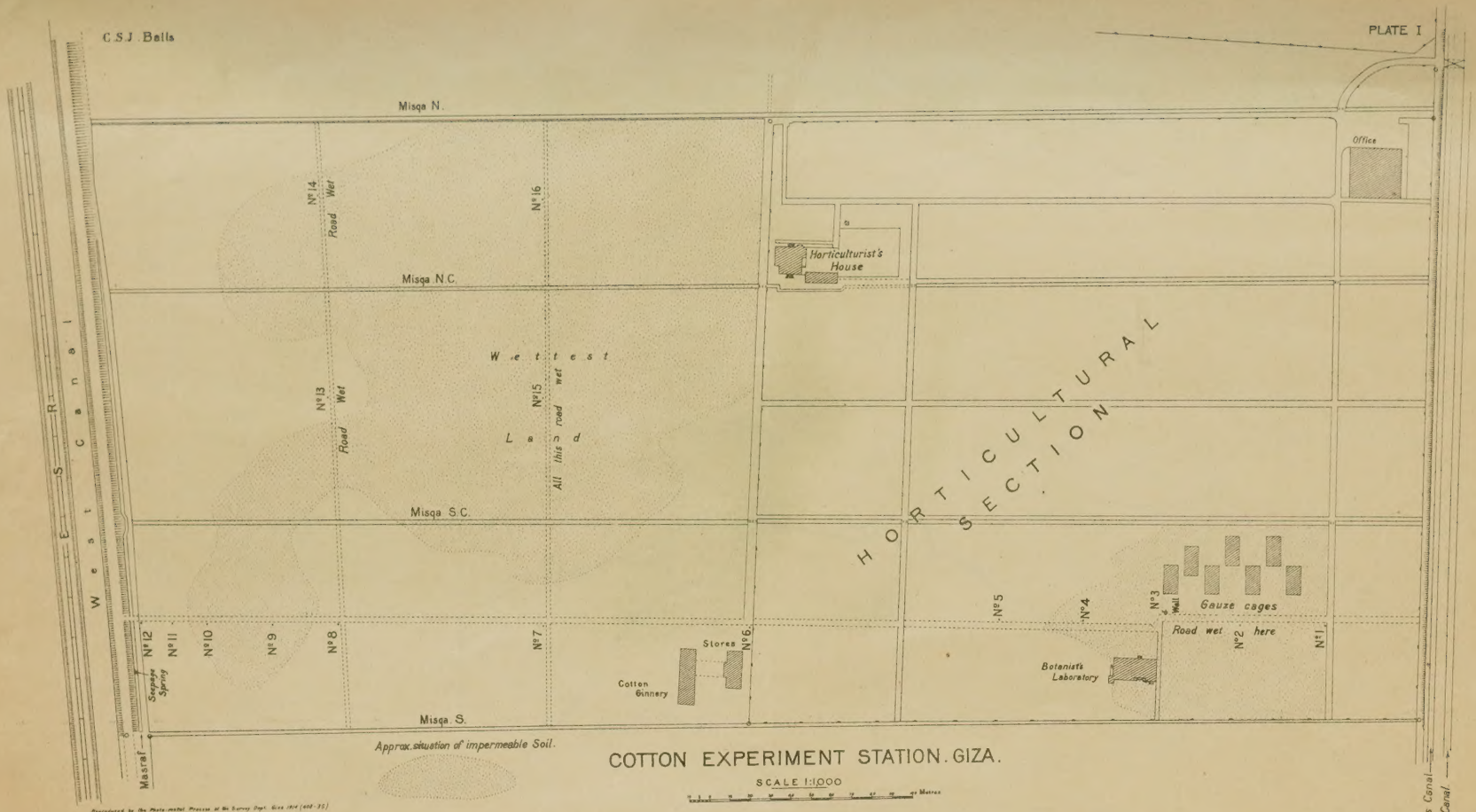
[1] The remaining wells are largely or entirely affected by surface water only. The volume water given at each watering varied from time to time and from well to well according to our judgement of the needs of the particular spot. Consequently the effects of a watering vary in magnitude.

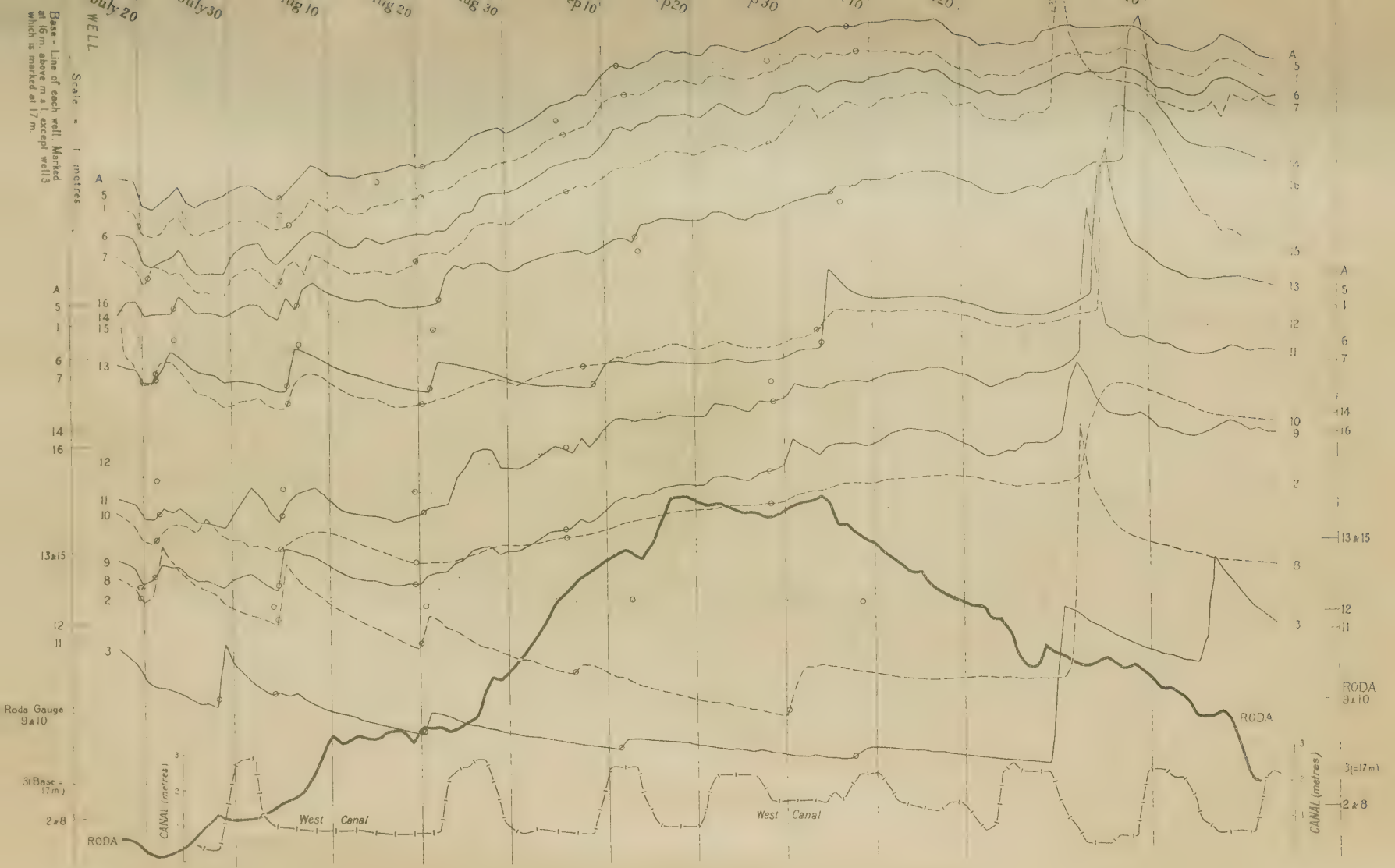
C.S.J. Balls

PLATE I



COTTON EXPERIMENT STATION. GIZA.

Reproduced by the Photo-mstel Process at the Survey Dept. Giza 1914 (408-35)


July 20
July 30
Aug 10
Aug 20
Aug 30
Sep 10
Sep 20
Sep 30
WELL
Scale
metres
Base - Line of each well Marked at 16 m. above m.s.l. except well 13 which is marked at 17 m.
A
5
1
6
7
16
14
15
13
12
11
10
9
8
2
3
13 & 15
Rods Gauge 9 & 10
3 (Base = 17 m)
2 & 8
RODA
CANAL (metres)
West Canal
RODA 3 & 10
3 (=17 m)
Reproduced by the Photo-lastil Process at the Survey Dept. Cairo 1941 (1400-38)

Curiously enough the records from No. 13 show the worst conditions, this well being almost entirely independent of outside influences, rising at once on watering, whereas No. 15 rises more slowly. The discrepancy, though slight, is probably due to the three-metre depth of the wells, and would be absent with wells of half the depth. It would seem that No. 15 is in connection with a larger bulk of fairly permeable loan within a clay envelope or cup, covered by a superincumbent sheet of clay through which the surface water has to find its way, thus raising the well-level slowly. The surface soil in this area is quite loamy, and when fallow it appeared to be excellent.

Well No. 12.—This well is unreliable. It is close up against the West Canal bank, and is entirely unaffected by the Canal. Along with 9, 6, and 7 it rises to a maximum which is 10 cm. higher than that of other free wells. Its later behaviour resembles that of a choked well, but it was free before the daily records began.

Well No. 11 is chiefly notable for the big effect produced by the Canal. It might be mentioned that in cutting a drain across the tails of the misqas parallel to the West Canal we crossed a natural sand bed at a depth of about 80 cm. below the surface, from which came a strong spring of water when the canal was filled. We have thus direct evidence of the escape of water into the land. The rise in well level produced by 200 cm. of water in the canal is about 20 cm. at No. 11, 15 cm. at No 14, 10 cm. at No. 16, 5 cm. at No. 5, and 3 cm. at No 1.

Wells Nos. 8, 9 and 10.—Though quite dissimilar, these may all be taken together. No. 8 lies to the east of a wet tongue which extends across the road southward, whereas No. 10 is at the worst part. At a depth of three metres, however, No. 8 is completely isolated, and is the saltest well on the land. No. 10 resembles No. 12, instead of the intervening No. 11, and is also suggestive of choking during early August No. 9 is affected mostly by surface water, and only to a slight extent by the West Canal, pointing to the intervention of a partition which is but slightly permeable; probably the point of the well had almost passed through the edge of the tongue of clay in which No. 8 is ensconced.

Well No. 3.—This well, with No. 8, is typical of impermeable soil. Being within a few centimetres of Well A, it is particularly interesting.

The form of the curve taken by the falling water in these impermeable wells should be noticed. The initial rapid fall is due to combined evaporation from the soil and the plants. The soil-evaporation diminishes after the first few days, and when the soil has been hood the loss must be almost entirely from the plant; since this loss is roughly constant from day to day in a short period, the falling curve becomes a straight line. The fact that most of the area under consideration was cultivated in wide-sown cotton prevents me from checking these assumptions on the basis of my direct determinations made in field crop. (Jour. Agric. Soc., 1913).

HIGHEST AND LOWEST LEVELS.

In the absence of any presentation of the detailed figures it may be useful to give the maximum and minimum levels attained by the wells during the period shown in the Plate II and before watering the berseem. The mean of the five minimum or maximum days has been taken, correct to 1 cm.

The wells are grouped in this table according to peculiarities of their maximum level. Figures for salt-content are added; these show higher concentration in the isolated wells, as would be expected during evaporation without drainage; the relatively high content of Well A is unexpected, and shows that its geological relations with Nos. 1 and 5 are not so direct as its hydrology would indicate.

RODA 1913.	Well Levels.		Salt content. (NaCl per million).	
	Minimum.	Maximum.	July 31, 1914.	Dec. 9, 1914.
	15·21	17·15	(misqas 5 per million).	
Well A	16·44	17·44	81	95
Well 1	16·47	17·46	22	22
,, 5	16·45	17·47	40	32
,, 16	16·48	17·44	40	34
,, 14	16·61	17·43	22	25
,, 11	16·64	17·47	36	22
Well 6	16·47	17·54	31	18
,, 7	16·45	17·53	31	25
,, 12	16·73	17·55	36	23
,, 9	16·67	17·52	44	22
Well 13	16·90	17·39	17	32
,, 15	16·81	17·30	114	115
,, 10	16·83	17·27	36	25
,, 2		17·32	87	122
,, 4		17·19	220	204
,, 3		17·12	129	136
,, 8		16·82	843	827

Soil salt-content at 50 cm. on Dec. 10th, 1914 ranged from 0·006 per cent to 0 046 per cent.

The distinction between the first and second groups is very clear, and all the latter show a fall in salt-content, but I must confess myself unable to advance an explanation as to why the components of each group should be so closely similar, unless by introducing hypothetical sand-beds of great extent.

The remarkable fact is that all of the wells (except two "isolated" ones) reached a *higher level than the Nile.* This is simple in the case of isolated wells, whose level may be raised to any point by surface watering, but it throws some unexpected light on the causes of the water-table rise, when seen in perfectly "free" wells as A and 1, and could only have been demonstrated in such an abnormally low flood as 1913.

The slow fall of the water during the winter was formerly thought to have been completely explained as due to drain-back from the western land underneath

the laboratory into the river, this water having seeped out from the flood. In this 1913 series, however, it is self-evident that although the rise of the river initiates the rise of the water-table in permeable soils, with inevitable consequent damage to the plants when the root is touched by the water, yet this rise is not exclusively due to this cause, even within a kilometre of the river.[1] Further, the continued rise of the water-table once the first damage has been done, is more due to surface and infiltration water; from a distance such water has been lifted or taken out of the river upstream and has flowed down more or less parallel to it. This superincumbent component was certainly responsible for a sur-elevation of 30 cm. on the land under discussion in 1913, and probably for very much more, since the mere subtraction of 17·15 m.A.S.L. from 17·45 m.A.S.L. allows nothing for gradient of the water-surface outward from the river.

The substantial leak which we have traced indubitably for half a kilometre from our Western Canal must be repeated in thousands of other places in this and other large canals. The amount escaping under this particular land was sufficient, roughly speaking, to raise all the permeable wells about half a centimetre, if spread over the whole period. Since we have good reason to believe that the cotton crop not only uses up all the water supplied to it during August, but also draws on the water-table to make up its balance of supply[2] it would seem that we have in these well-curves a very strong piece of circumstantial evidence to show that infiltration from canals during flood is an important factor in augmenting the height of the autumn water-table, downstream of them though the initial rise may be due to long-distance subterranean infiltration from the river.

My thanks are due to Mr. Holton, for supervising the observations, to Shaban Abd el Aal who took them, and to Mr. Weinsteiner.

The work was done during my tenure of the post of Botanist to the late Department of Agriculture.

SUMMARY.

1. This paper presents in graphic form only, the results obtained by measurements of seventeen tube-wells on an area of thirty feddans (acres) at Giza, near Cairo

2. The extreme complexity of the subsoil structure leads to most various conduct in the different wells, for the causes of which I have advanced most tentative explanations.

3. Different wells were differently affected by surface irrigation, by seepage from misps (land channels), by infiltration from a canal, by the Nile flood, and by the down-flow of water underground from Upper Egypt, this water coming from infiltration out of canals, or out of the river, or from surface irrigation or from all these sources

4. The well-level in freely permeable soil rose higher during 1913 than the Nile flood, which had previously been considered as the primary cause of such elevation on the site in question.

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[1] See Willcocks and Craig. "Egyptian Irrigation," 1913. I. 12 for a similar conclusion independently developed.

[2] The writer, Jour. Agric. Soc., 1913, and F. Hughes, Cairo Sci. Soc., Lecture, Nov. 1913.

5. The water-table, so far from being stagnant and peaceful, is continually throbbing in response to hydraulic impulses received in all directions and from unknown distances. Except in isolated clay basins it is never at rest, and even there it is slightly troubled by meteorological changes.

6. Irrigation has raised the level of the natural water-table of Egypt.

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